The invention provides a structure having a porous metal body firmly attached to a solid metal carrier as in figure 1. This composite structure is built up from a porous body (10) which is at least partially made of aluminium or an aluminium alloy and a solid metal carrier (20) made of aluminium or an aluminium alloy. There is also a formed in situ layer (30) obtainable by thermal spraying. This layer is bonded directly to at least a portion of said solid metal carrier material (20) and the porous body (10) is sintered to said layer (30) which is bonded to the solid metal carrier. Further, the present invention provides a method for firmly attaching a porous metal body to a solid metal carrier and the use of those structures in heat exchangers, electronic assemblies and heat sinks. More specifically, the invention provides a firmly bonded aluminium construction containing porous aluminium material and a solid aluminium carrier.
Description

COMPOSITE ALUMINIUM OR ALUMINIUM ALLOY POROUS STRUCTURES

Field of the invention

[0001] The present invention relates to bonded aluminium or aluminium alloy metal materials. More specifically, the invention relates to a structure of porous aluminium or aluminium alloy material attached to a solid aluminium or aluminium alloy carrier.

[0002] Further, the present invention provides a method for attaching a porous metal body to a solid metal carrier by sintering and the use of those structures in heat exchangers, radiators, electronic assemblies and heat sinks. More specifically, the invention provides a firmly bonded aluminium construction containing porous aluminium material and a solid aluminium carrier. Even more specifically, the present invention provides a firmly bonded aluminium construction containing porous aluminium material and a solid aluminium carrier that can withstand high temperatures, temperature shocks and is corrosion resistant.

Background of the invention

[0003] As a consequence of the use of porous metal bodies in heat-exchanging devices, a good heat conducting contact between the porous metal body and the solid metal carrier is indispensable for a proper functioning of the heat-exchanging devices. This is particularly relevant having regard to the fact that only 5 to 30% of the surface of the solid metal carrier is in contact with the porous metal body. Establishing a good thermal/metallic contact can reduce the total dimensions of a heat-exchanging device considerably and thereby reduce material costs and space.

[0004] The art already describes a lot of applications of porous metal bodies in heat-exchanging devices. US 6397450, describing a method of cooling an electronic power module, achieved bonding between a metallic foam and the thermal base (with metallised surface) through soldering, active brazing or simply brazing. EP 1553379 Aalso states that the connection between shell and metal sponge, as an example of a porous metal body, can be simply made by means of soldering or welding.

[0005] A porous aluminium or aluminium alloy body is properly attached to a solid
aluminium or aluminium alloy carrier when one cannot pull the porous structure off the solid structure, i.e. there is a good mechanical bonding.

[0006] One can achieve a proper mechanical bond between a porous metal body and a solid metal carrier, by, for example soldering, but as this method uses an extra material, heat dissipation from carrier to porous body or the other way around can be distorted and the extra material, e.g. zinc and/or a zinc alloy, can give corrosion problems at the bonding place and even have the effect of a lower (heat) conductive layer. It also gives an end product which is limited in use for heat applications, i.e. limited by the melting temperature of the Zn in the solder.

[0007] Another way of achieving a firm bonding between a porous body and a solid metal carrier is brazing. This technique uses an extra material either in the form of a three-layer sheet, which is put between the porous metal structure and the solid metal carrier when put in an oven; or in the form of a brazing paste, which also brings extra material in the form of fluxes and filler material into the brazing process thereby also making the bonding process more complex. Both brazing methods result in a lower heat transfer capacity of the system, in comparison with a sintered porous metal/solid carrier connection.

[0008] Welding could also be used, but due to the porous nature of the porous material, the pressure needed in welding would simply destroy the porous material.

[0009] The only method that proved to be a good solution for attaching a porous aluminium or aluminium alloy structure to a solid aluminium or aluminium alloy material, resulting in a good metallic bonding which can withstand high temperatures and is corrosion resistant, is sintering. But this turned out to be a rather difficult method as both aluminium pieces have to be heated near the solidus point of aluminium or the aluminium alloy and the necessary pressure used in the sintering process causes the porous structure to be damaged. The operating window for getting a good bonding between the pieces and not damaging the porous structure is, especially
for aluminium and the aluminium alloys, very small.

[0010] A less narrow operating window is thus desired to be able to use this sintering method in a production environment, where temperatures in the oven are subjected to larger fluctuations than on a lab scale.

[0011] These and other difficulties of the prior art have been overcome according to the present invention which provides for the fabrication of firmly and uniformly attached materials, and the structures so fabricated.

Summary of the invention

[0012] In a first aspect the present invention provides an alternative joined structure of aluminium or aluminium alloy materials.

[0013] In a second aspect the present invention provides a novel metallic structure having an optimal heat conductance throughout the complete structure, thereby providing a heat transfer path from the metal carrier to the porous metal material or vice versa. Accordingly, in a further aspect the invention provides a novel heat exchanger.

[0014] In a third aspect the invention provides a condensing boiler wherein the heat exchanger part comprises such an alternative joined structure of aluminium or aluminium alloy materials.

[0015] The composite structure is built up from a porous metal body which is at least partially made of aluminium or an aluminium alloy and a solid metal carrier material made of aluminium or an aluminium alloy. There is also a formed in situ layer obtainable by thermal spraying, e.g. starting from a metal powder or a metal wire. This layer is bonded directly to at least a portion of said solid metal carrier material and the porous structure is sintered to said layer which is bonded to the solid metal carrier material. Preferably, the porous structure is an open- or closed- cell metal foam, a metallic spacer material, a knitted wire mesh or a metal fibre fabric.

[0016] The thermal sprayed metal powder or wire is preferably aluminium or an aluminium alloy, more preferably AlSi. The thickness of the thermal sprayed layer is preferably from 20 µm to 500 µm, more preferably the layer is between 50 µm to 250 µm, even more preferably between 75 µm
and 150 µm.

[0017] In a further aspect the invention provides a method for firmly joining a porous metal body to a solid metal carrier. The method for attaching this porous metal body to a solid metal carrier wherein the porous metal body is made of aluminium or an aluminium alloy and the solid metal carrier is made of aluminium or an aluminium alloy. The method comprises thermal spraying a layer of aluminium or aluminium alloy, e.g. powder or wire, to the solid metal carrier and consecutively sintering the porous metal body onto this thermal sprayed layer on the solid metal carrier. Preferably, the metal (powder or wire) used for thermal spraying is an AlSi. Preferably, the porous body is an open- or closed-cell metal foam, a metallic spacer, a knitted wire mesh or a metal fibre fabric.

[0018] The invention thus provides a method for attaching a porous aluminium or aluminium alloy body to a solid aluminium or aluminium alloy carrier forming a good metallurgical bonding.

The novel metal structure is an assembly of a porous aluminium or aluminium alloy body attached to a solid aluminium or aluminium alloy carrier wherein the solid metal carrier has a layer of aluminium or aluminium alloy particles obtained via thermal spraying.

[0019] According to the present invention, thermal spray processing is used to form the aluminium or aluminium alloy layer in situ on a solid aluminium or aluminium alloy carrier.

[0020] Thermal spray processing is a generic term for a broad class of related processes in which molten droplets of metals, ceramics, glasses and/or polymers, singly or in combinations, are sprayed onto a surface. In principle, any material with a stable molten phase can be thermally sprayed. Deposition rates are very high in comparison to alternative coating technologies. Deposit thicknesses of, for example, 0.1 to 1.0 mm for fully continuous layers are common. If desired, thicknesses greater than 1 cm can be achieved with some materials. Thickness is controlled,
for example, by rastering the spray nozzle back and forth over the part, and although this is a line-of-sight process, all areas can be coated by reorienting the substrate and the spray nozzle relative to one another, manually or robotically. Various irregular surface configurations can thus be accommodated. In situ formation is to be distinguished from a process where the skin is formed at some other location and applied to the porous substrate as a pre-formed sheet. An in situ process of formation according to the present invention deposits a fluid form of the material that forms the layer at the site where the layer is to be formed, and the layer is formed by the build up of solidified material at that site. In some cases metallurgical bonds can be achieved between the carrier and the layer. That is, the material of either the layer or the carrier is soluble to some extent in that of the other. Such bonds are extremely strong. The thickness of the layer is defined by the structural requirements of the application and is obtained by rastering the thermal spray nozzle over the part until the required thickness is achieved.

Thermal spray techniques are well known. See, for example, Lech Pawlowski, "Science & Engineering Of Thermal Spray Coatings", (J. Wiley & Sons, 1995).

Plasma spraying appears to be the most common form of the thermal spraying operations for powders. In a plasma spraying process, an inert gas is passed through an electric arc, thus creating an extremely hot ionized gas. The desired coating material, in powder form, is injected into the hot ionized gas stream. In the gas stream at least a substantial portion of the powdered coating material becomes partially molten or plastic. In general, the particles are not fully melted. The fluid particles are quenched and bonded when they strike the surface of the substrate. The inert gas is delivered under pressure to the electric arc so that it picks up the molten or plastic coating material and accelerates it onto the surface of the substrate. At the substrate surface a layer-by-layer build-up takes place through interparticle bonding and sintering reactions as the spray nozzle is rastered back and forth over the surface.

High velocity oxy-fuel (HVOF) thermal spray deposition processes involve
the combustion of an oxygen-fuel mixture to generate a stream of gas that heats and accelerates the powdered feed to supersonic velocities. The combination of very high particle velocities and relatively low flame temperatures makes possible the production of coatings with improved mechanic properties and good thermal properties. This process is particularly suited to the application of ceramic coatings on silicon carbide foam substrates. In addition to combustion and plasma heaters, other means of heating, such as, resistance heaters, induction heaters and the like, can be used.

[0023] One type of wire thermal spraying is combustion wire thermal spraying. The process entails feeding a wire stock material through a combustion chamber. In conventional wire gun constructions, the wire is generally fed axially through the gun at a controlled rate by a pair of feed rollers which grip the wire and rotate to push the wire through the combustion chamber, which may include a gas head nozzle arrangement and an air cap. The nozzle arrangement generally includes a ring of burner jets or other heating mechanism surrounding the wire passage through which a combustible gas mixture is passed and burned. The heat of the flame heat-softens the leading tip of the wire as the tip passes into the air cap and a high velocity stream of blast gas is directed against and impinges on the softened tip atomizing the metal (or other heat-fusible material) in the form of particles. These molten particles are propelled from the gun onto a substrate to form a coating.

[0024] The controlling parameters in thermal spraying operations generally include the amount of arc energy or combustion energy, and the feed (powder or wire) material composition, size, shape, feed rate, and velocity. The adjustment of these parameters to achieve a desired result is well understood in the art. In generally, the particles that are projected onto a substrate in a thermal spraying operation are not melted completely through. Also, particles that do not melt can be incorporated into the powders to form inclusions in meltable matrix materials in the coatings. As will be understood by those skilled in the art, the spraying parameters are optimized for a particular application based on preliminary tests. For
example, in general, for an otherwise constant system, increasing the velocity of the carrier gas increases the density of the thermal sprayed coating.

The powdered feed materials that are suitable for use in thermal spray procedures generally range in size from approximately 250 to 2 microns. Wire feed material is commercially available as wires of 1.6mm in diameter. The carrier gas that entrains and carries the particles is generally the same as the plasma or combustion gas.

[0025] The layer formed in situ according to the present invention, conforms exactly to the surface of the solid carrier and, therefore, is bonded tightly and directly to the surface of the solid carrier.

[0026] Other objects, advantages, and novel features of the present invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings.

[0027] Definition

[0028] As used herein the term AISi means any aluminium silicon mixture or alloy containing enough silicon to have considerably lower melting point than the other bodies to be joint (porous metal and solid carrier).

Brief description of the drawings

[0029] The invention will now be described into more detail with reference to the accompanying drawing wherein

- FIG. 1: schematic representation of one embodiment of a composite porous structure

[0030] Reference list of used numbers in the drawings

10 porous aluminium or aluminium alloy material
20 solid aluminium or aluminium alloy carrier
30 thermal sprayed metal layer

Description of the preferred embodiments of the invention

[0031] The invention provides a structure having a porous metal body firmly attached to a solid metal carrier material as in figure 1. This composite
structure is built up from a porous structure (10) which is at least partially made of aluminium or an aluminium alloy and a solid metal carrier material (20) made of aluminium or an aluminium alloy. There is also a formed in situ layer (30) obtainable by thermal spraying starting from a metal powder or metal wire. This layer is bonded directly to at least a portion of said solid metal carrier material (20). The porous structure (10) is sintered to said layer (30) which is bonded to the solid metal carrier material.

[0032] Tests were set up to compare the heat transfer obtained when using different techniques for joining an AlSi 6060 carrier with an open-celled Al99 foam. Conditions for thermal spray were:
AlSi powder: Al-12%Si (Metco 52C-NS); process: plasma spraying; plasma spray gun, with standard nozzle; Sample preparation: grit blasting using F60 grit; Ar flow (60 psi # 56 orifice); He flow (120 psi # 97 orifice); current = 350 A; spray distance = 100 mm; 1 pas; layer thickness between 100 - 300 µm
with subsequent sintering wherein the conditions for sintering were:
atmosphere: vacuum; 1.10⁻⁴ mbar/time = 130 - 200 min; temperature = 620-630 °C; load = 13 - 14 g/cm²; sample size: 100 x 100 mm and 100 x 300 mm
* Conditions for classical sintering were: atmosphere: vacuum; 1.10⁻⁴ mbar; time = 130 - 200 min; temperature = 620-630 °C; load = 13 - 14 g/cm²; sample size: 100 x 100 mm
* Conditions for brazing were: sample size: 100 x 100 mm; brazing sheet: 4xxx/3xxx/4xxx aluminium alloys; atmosphere: N₂; temperature = 620°C; clamped between inconel springs
* Conditions for soldering were: sample size 100 x 100 cm; soldered with Zn-based soldering wire; atmosphere: air; temperature: both 6060 plate and Al99 foam heated to 470°C and pre-coated with solder, then pressed to each other and cooled.
Results for sample sizes of 100 x 100 mm
Above results show that sintering + AISi thermal sprayed layer gives equal or better bonding quality as compared to sintering, brazing and soldering and that sintering + AISi thermal sprayed layer gives equal or better heat transfer as compared to sintering, brazing and soldering.

On samples of 100 x 300 mm it was shown in a batch oven that sintering aluminium foam on a larger aluminium substrate is a difficult process to control. The difficulty lies in creating good bonding without flattening the foam. Small differences in temperature within the heated zone of the batch oven already result in some areas of good bonding and other areas of no bonding at all between porous metal and carrier on the same sample. The brazing process was shown to give good bonding without flattening the foam; but experiments on small samples revealed it was shown that this process reduces the heat transfer 8.5 - 10 % compared to sintering (see table above). Hence, sintering is the preferred joining method.

Sinter experiments on large substrates, using samples provided with and without thermal spray layer indicated that the layer of AISi enables ('aids') to sinter foam on large substrates. Qualitative evaluation of the bonding upon sintering for 200 min at 620-630°C in vacuum: - with AISi thermal spray layer: foam CANNOT be pulled manually from substrate; - without AISi thermal spray layer: foam CAN be pulled manually from substrate (i.e. no connection or connection of poor quality).

Further tests were performed to further explore the operating window for sintering such porous aluminium or aluminium alloy materials to a thermal sprayed solid aluminium or aluminium alloy carrier. Tests were carried out with AISi 6060 carriers and open-celled Al99 foam.
Sample size: 100 x 100 mm, thermal spray conditions same as above, sinter conditions: atmosphere: vacuum; $1.10^{-4}$ mbar/time = varied; temperature = 620 °C; load = varied:

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<tr>
<td>620°C, 60 min, 14 g/cm²</td>
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<td>620°C, 130 min, 7 g/cm²</td>
<td>Very good</td>
<td>224 ± 3</td>
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[0036] The heat transfer score obtained by variation in time and weight used for sintering also proves that the operating window for obtaining a good metallurgic bonding between the aluminium foam and AlSi 6060 carrier is much broader, thus enabling sintering of aluminium parts on an industrial scale level in a continuous oven where production parameters are more prone to fluctuations.

[0037] These sintered + AlSi thermal sprayed composites of the invention can then be used in a novel heat exchanger. These composites, having a good metallurgical and corrosion resistant bonding, can also be incorporated in a condensing boiler, thereby enabling the system of condensing the flue gasses to retain as much energy as possible from the flue gasses. Due to the high heat transfer capacity of the sintered composite structure of the invention, a volume reduction of a condensing boiler can be obtained, without giving in on the condensation capacity of the system.

[0038] While a few embodiments of the teaching of the invention are described by way of examples, it is to be understood that these are illustrative only and the scope of the invention is to be defined solely by the appended claims when accorded a full range of equivalence, many variations and modifications naturally occurring to those of skill in the art from a perusal hereof.
Claims
1. A structure comprising a porous body at least partially made of aluminium or an aluminium alloy and a solid metal carrier material made of aluminium or an aluminium alloy, a formed in situ layer obtainable by thermal spraying, said layer bonded directly to at least a portion of said solid metal carrier, said porous structure sintered to said layer.
2. A structure according to claim 1, wherein said porous body is a metal foam.
3. A structure according to claim 2, wherein said metal foam is an open cell metal foam.
4. A structure according to claim 2, wherein said metal foam is a closed cell metal foam.
5. A structure according to claim 2, wherein said porous body is a metallic spacer material.
6. A structure according to claim 1, wherein said porous body is a knitted wire mesh.
7. A structure according to claim 1, wherein said porous body is a metal fibre fabric.
8. A structure according to any of the previous claims, wherein the thermal spraying is performed using a metal material made of aluminium or an aluminium alloy.
9. A structure according to claim 8, wherein said thermal spraying material is AISi.
10. A structure according to claim 8, wherein said thermal spraying material is in the form of a metal powder.
11. A structure according to claim 8, wherein said thermal spraying material is in the form of a metal wire.
12. A structure according to any of the preceding claims, wherein the thickness of said layer is from 20 µm to 500 µm, preferably from 50 µm to 250 µm, even more preferably from 75 µm to 150 µm.
13. Method for facilitating the attachment of a porous metal body to a solid metal carrier, providing: -a porous metal body made of aluminium or an aluminium alloy; - a solid metal carrier made of aluminium or an aluminium alloy; - a thermal sprayed layer of aluminium or aluminium alloy onto said solid metal
carrier, - sintering said porous metal body onto said thermal sprayed side of said solid metal carrier; said thermal sprayed layer enlarging the operating window of the sintering process.

14. The use of the structure as in claims 1 to 12 in a heat exchanger.

15. A heat exchanger comprising a structure as defined in claims 1 to 12.

16. A condensing boiler comprising a structure as defined in claims 1 to 12.
**INTERNATIONAL SEARCH REPORT**

International application No

PCT/EP2008/053486

A. CLASSIFICATION OF SUBJECT MATTER

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According to International Patent Classification (IPC), both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B22F B32B C22C C23C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, COMPENDEX, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents:
  - 'A': document defining the general state of the art which is not considered to be of particular relevance
  - 'E': earlier document but published on or after the international filing date
  - 'L': document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
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  - 'Z': document member of the same patent family

Date of the actual completion of the international search: 25 June 2008

Date of mailing of the international search report: 04/07/2008

Name and mailing address of the ISA:
European Patent Office, P.B. 5818 Patentlaan 2
NL- 2280 HV Rijswijk
Tel (+31-70) 340-2040, Tx. 31 651 eponl,
Fax: (+31-70) 340-3016

Authorized officer

Morra, Valentina
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